THE CAUSE AND ELIMINATION OF NIGHT ERRORS IN RADIO DIRECTION-FINDING.*

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SUMMARY.

The paper describes experiments which have been carried out with a view to obtaining more conclusive evidence as to the causes of the apparent variations in bearings observed under certain conditions on wireless direction-finders. In the course of the experiments the Adcock "four-aerial" direction-finder has been developed, and with its aid it has been shown that the actual deviation in azimuth of wireless waves is practically negligible. These experiments thus constitute a proof that the variable errors observed on closed-coil direction-finders at night are caused by downcoming waves arriving from the upper atmosphere and polarized with the electric force in a horizontal plane. The investigation also indicates the possibility of the Adcock system being developed into a practical direction-finder which is free from night errors, and those errors associated with observations on aircraft transmissions made at a ground direction-finding station.

(1) OBJECT OF THE PRESENT PAPER.

The object of a large proportion of the investigations carried out by the present authors for the Radio Research Board during the past few years has been to ascertain definitely the cause of the apparent variations in bearings experienced on closed-coil direction-finding apparatus during the "night" periods. Some of these investigations have led to the development of methods of distinguishing between the electric and magnetic components of wireless waves, and of the separate measurement of their intensity and direction. This portion of the work has recently led to a definite proof of the existence of downcoming waves at the earth's surface with components of suitable polarization and sufficient intensity to account for a large proportion of the night errors experienced.†

In this manner the theory originally advanced by T. L. Eckersley ‡ in 1921 to account for the apparent variations in the direction of arrival of wireless waves has been adequately confirmed; and it is now evident that these variations are caused by the action of the horizontal components of electric force in the downcoming waves on the horizontal parts of the direction-finding loops. A good discussion of these effects and the associated phenomena is given in Keen's book on the subject of wireless direction-finding.§

It is generally assumed that the downcoming waves have travelled via the upper regions of the earth's atmosphere without deviating laterally from the great-circle plane through the transmitter and receiver. This assumption has, however, not been sufficiently well justified in the past; and the presence of the downcoming waves has hitherto made it difficult to prove whether the direct waves travelling along the earth's surface have not also suffered any lateral deviation. Another portion of the authors' investigations has therefore been made to ascertain to what extent, if any, such lateral deviation exists. The problem is one of more than pure scientific interest; for it is evident that, if directional receiving apparatus can be devised which shows the absence of lateral deviation, we are at once provided with a direction-finder which is free from the variable night errors that place such a serious limitation on closed-coil direction-finders. The present paper describes the experiments which have been carried out with these objects during the past 18 months.

(2) SUGGESTIONS AND ATTEMPTS BY PREVIOUS WORKERS.

The problem involves essentially the production of an apparatus which will measure the horizontal component of the direction of arrival of wireless waves, irrespective of their angle of incidence at the earth's surface or their state of polarization.

Three methods of attacking this problem have previously been described. In a patent filed in 1919, F. Adcock * described a direction-finding arrangement in which the aerials were mounted and connected in such a manner as to ensure that only the vertical parts were acted upon by the arriving waves. In this way he proposed to eliminate the errors which are caused by the effect of the horizontal electric field on the receiving system. This arrangement consisted essentially of four vertical aerials spaced at the corners of a square; the aerials at the extremities of a diagonal formed a pair and were connected in opposition to the field coils of a radiogoniometer. Provided that the horizontal members of the system have no effective E.M.F. induced in them, it is clear that the current in the field coils is due entirely to the phase difference of the E.M.F.'s induced by the vertical component of the electric force of the arriving waves. This current will thus depend only on the horizontal direction of arrival of the waves relative to the system.

In the paper already mentioned,† T. L. Eckersley

* Reprinted from *Journal I.E.E.*, 1926, vol. 64, p. 831.

† R. L. SMITH-ROSE and R. H. BARFIELD: "An Investigation of Wireless Waves arriving from the Upper Atmosphere," *Proceedings of the Royal Society*, A, 1926, vol. 110, p. 580.

‡ T. L. ECKERSLEY: "The Effect of the Heaviside Layer on the Apparent Direction of Electromagnetic Waves," *Radio Review*, 1921, vol. 2, pp. 60 and 231.

§ R. KEEN: "Direction and Position Finding by Wireless," 1922, p. 164.

* F. ADCOCK: "Improvement in Means for Determining the Direction of a Distant Source of Electromagnetic Radiation," British Patent 130490/1919.

† T. L. ECKERSLEY, loc. cit., p. 239.

suggested that any lateral deviation of wireless waves from the great-circle plane through transmitter and receiver could be measured by employing a receiver in which each of the ordinary closed loops of the Bellini-Tosi arrangement is replaced by two loops in the same plane connected together in series and so that their E.M.F.'s oppose each other. With such an arrangement the effective E.M.F. induced therein will be entirely due to the phase difference between the individual E.M.F.'s in the two loops resulting from their spacing. It is then evident that a wave arriving in a direction at right angles to the plane of the loops will produce no resultant E.M.F. in the circuit, whatever may be the angle of incidence or state of polarization of the arriving waves.

In 1921, G. M. Wright and S. B. Smith * published an account of experiments carried out with a direction-finder connected in such a manner as to give the heart-shaped polar diagram for reception. These experiments showed that, under conditions when large variations in apparent bearings were obtained on the ordinary direction-finder, the position of the heart-shape minimum remained constant although the actual shape of the polar reception curve altered considerably. The agreement of the experimental results with those predicted from Eckersley's theory served as a useful confirmation of this theory. The accuracy of such experiments, however, largely depends upon the purity of the minimum and, as Wright and Smith pointed out in their paper, the heart-shaped minimum only remains pure when the downcoming waves are arriving at a reasonably small angle to the horizontal (i.e. a large angle of incidence). In some of the authors' recent experiments, however, angles of incidence as small as 16° to the vertical have been measured,† and the behaviour of the heart-shaped diagram under such conditions is a matter for further investigation.

As far as the authors are aware, no account of the practical working of either of the above systems as direction-finders has yet been published, although the heart-shape circuit arrangement is now in common use for the determination of the " sense " of wireless bearings. Quite recently, however, a directional receiving system comprising two spaced loops mounted in a common vertical plane has been described by H. T. Friis.‡ This arrangement has been developed with a view to obtaining directional selectivity in ordinary wireless reception, and not as an application to direction-finding.

(3) Early Experiments at the Radio Research Board's Station, Slough.

(*a*) *Double loop method.*—In the first experiments, a modification of Eckersley's suggested method was employed. Instead of using two pairs of large double loops at right angles, a single pair of small loops was constructed and arranged in a vertical plane so as to be rotatable about a vertical axis.

* G. M. Wright and S. B. Smith: "The Heart-shaped Polar Diagram and its Behaviour under Night Variations," *Radio Review*, 1921, vol. 2, p. 394.
† R. L. Smith-Rose and R. H. Barfield, loc. cit., p. 612.
‡ H. T. Friis: "A New Directional Receiving System," *Proceedings of the Institute of Radio Engineers*, 1925, vol. 13, p. 685.

The E.M.F. induced in such a system by a single wave is given by the expression :—

$$e = K \sin \frac{2\pi d \sin \theta}{\lambda} \cos \psi \, (\alpha \sin \psi + \beta \cos \psi) \quad . \quad (1)$$

where K is a constant for loops of a given area,

d = distance between the centres of the loops (assumed small compared with the wave-length λ),

ψ = angle between plane of loops and horizontal direction of waves,

θ = angle of incidence of the waves at the earth's surface,

α = horizontal component of magnetic field of waves in great-circle plane through transmitter and receiver,

β = horizontal component of magnetic field of wave perpendicular to α.

The above expression for the induced E.M.F. becomes zero when $\psi = 90°$, so that there is a zero or " minimum " position of the system when the plane of the coils is at

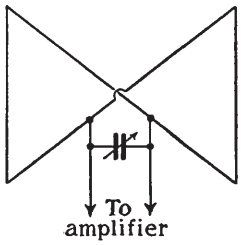

Fig. 1.

right angles to the horizontal direction of arrival of the waves, whatever may be their state of polarization or angle of incidence. It should be noted that this is not necessarily the only minimum which will be experienced in the rotation of the coil from 0° to 180°, since it is quite possible to have a second minimum at the value of ψ for which $\tan \psi = -\beta/\alpha$.

For simplicity of construction in the practical arrangement, the loops were made triangular in shape and consisted of a single winding in the form of a figure 8, as depicted in Fig. 1. These loops were erected in a hut which was suitably screened for the elimination of antenna effect, and the remainder of the receiving circuits and the amplifiers were adequately screened from the direct effects of the arriving waves. When the arrangement was tested it was found to work satisfactorily on near-by stations; but owing to the fact that its reception factor is differential in nature, it was not sufficiently sensitive for operation on transmissions from the more distant stations. Hence it was not possible to use the apparatus under the conditions which give rise to the usual night phenomena in radio direction-finding. In the absence of a much more sensitive amplifier, the only methods of increasing the strength of the received signals would be either to increase the distance between the loops (d), or to adopt Eckersley's suggestion of employing large fixed loops on the Bellini-Tosi plan. In regard to the last alternative, it is seen from equation (1) that the E.M.F. is not propor-

tional to cos ψ, and as the operation of the Bellini-Tosi radiogoniometer depends upon such a cosine law, this method cannot be adopted for the present case. Up to the present time no experiments have been made with loops separated by a greater distance, for, as will be seen below, the use of Adcock's method has been found to give more successful results.

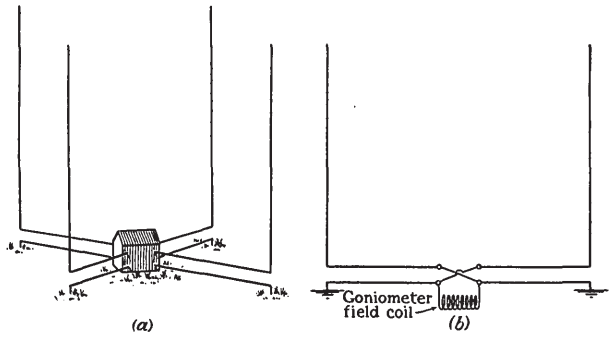

FIG. 2.

(*a*) Sketch of system. (*b*) Elevation of single pair of aerials.

(*b*) *Adcock's system.*—The simplest form which this system can take is probably that shown in Fig. 2 where each of the four aerials is earthed at a point vertically beneath it, but the earth lead is taken horizontally to the receiving hut at the centre of the system and back again. In Fig. 2 (*b*) only one pair of aerials is depicted to show the method of connecting the aerials in opposition through the field coil of the radiogoniometer. Such a mode of connection should have the effect of rendering any E.M.F.'s induced in the horizontal members of the system by the arriving waves equal and opposite with regard to the circuit " aerial-field-coil-earth," so that the net E.M.F. induced in this circuit is that due to the phase difference of the individual E.M.F.'s induced in the two vertical members. This E.M.F. is given by the equation

$$e = KZ\frac{2\pi d}{\lambda}\cos\psi \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where K is a constant for a given aerial system,

Z = vertical electric force,

d = distance between the aerials,

ψ = angle between direction of travel of the wave and the line joining the aerials.

Since the E.M.F. is proportional to cos ψ, it is clear that two pairs of such aerials may be used with a radiogoniometer in exactly the same manner that this instrument is used with the fixed loops of the Bellini-Tosi direction-finding system.

Experiments carried out with the above arrangement as in Fig. 2 showed that, due probably to stray capacities to earth, the horizontal E.M.F.'s induced in the system were not balanced out, and gave rise to serious errors.

(4) Attempted Improvement of Adcock's System.

With a view to overcoming the difficulty just mentioned, an attempt was next made to screen the whole of the horizontal portion of the system from the effects of the arriving waves. Previous experience had shown that in order to screen an aerial adequately, it was necessary for the screen to project beyond the aerial by a considerable length. The system finally adopted for the present case is depicted in Fig. 3, which shows one pair of aerials with the horizontal members contained within a screening trunk formed of a number of parallel wires. At their inner ends these wires were joined to the metallic lining of a screened hut which contained the whole of the receiving apparatus and the operator. Tests of the effectiveness of this screening arrangement were made by measuring the directional properties of the four individual aerials. These measurements unfortunately showed that the attempted screening of the horizontal portion of the aerials had been unsuccessful. The explanation of this result is probably that, whilst the screen effectively prevented any E.M.F. being induced directly in the horizontal members of the aerial system, the vertical component of the secondary electric field resulting from the currents in the screen itself, induced E.M.F.'s in the vertical portions of the

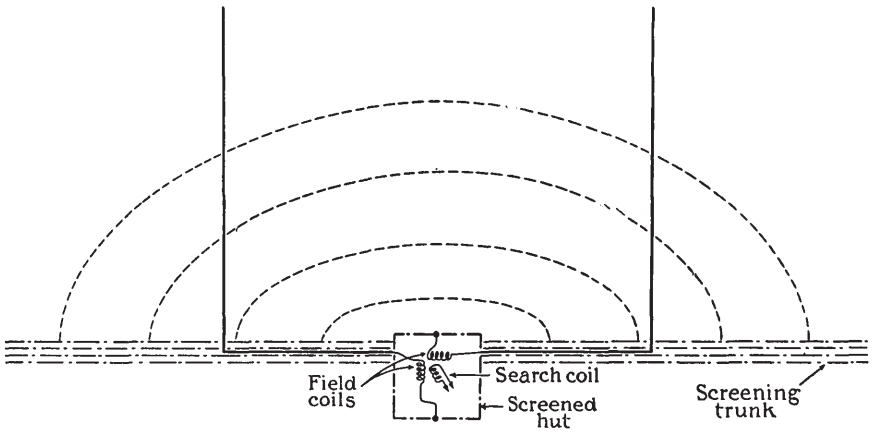

FIG. 3.

aerials (see Fig. 3). Since the currents in the screen are produced by the horizontal component of the electric force in the arriving wave, the condition that this component shall have no effect on the system is not fulfilled.

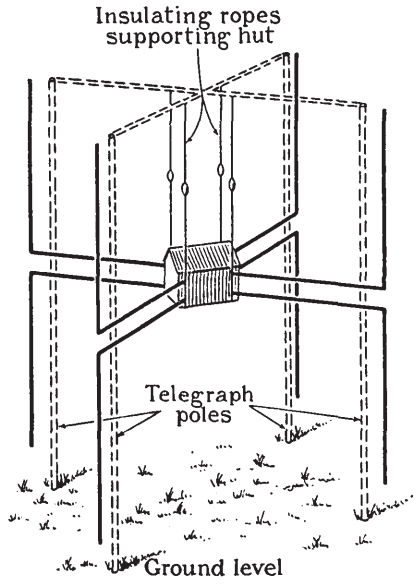

FIG. 4.

(5) FORM OF ADCOCK'S SYSTEM FINALLY ADOPTED.

It was now decided to revert to the alternative arrangement described by Adcock * in which the vertical aerials are comprised of complete Hertzian oscillators with leads taken horizontally from their mid-points to the receiving apparatus in the screened hut. In order

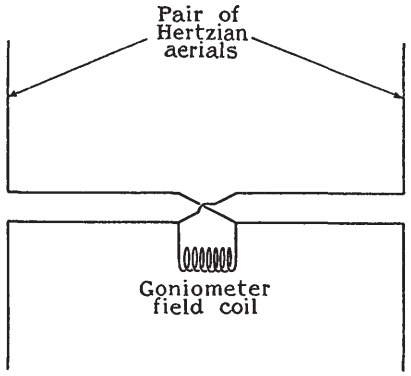

FIG. 5.

to maintain symmetry this of course necessitates the raising of the hut with the apparatus and operator to the level of the centre of the aerial system some 20 ft. above the ground. For the support of the aerial wires, four poles were available 44 ft. high, situated at the corners of a 20-ft. square. The receiving hut was placed at the centre of this system, being suspended by insulated steel ropes from cross beams attached to the poles, to reduce to a minimum its capacity to earth or to other structures.

* F. ADCOCK, loc. cit.

The arrangement is shown diagrammatically in Fig. 4, the circuit being as given in Fig. 5. By this reduction of the capacity to earth of the various parts of the system it was anticipated that the E.M.F.'s in the horizontal members would completely balance each other, and thus the system would be rendered free from the effects of any horizontal electric fields. The fulfilment of this condition was verified; first, by measuring the directional properties of the individual aerials as formerly; and secondly, by comparing the induced currents in the upper and lower halves of the same

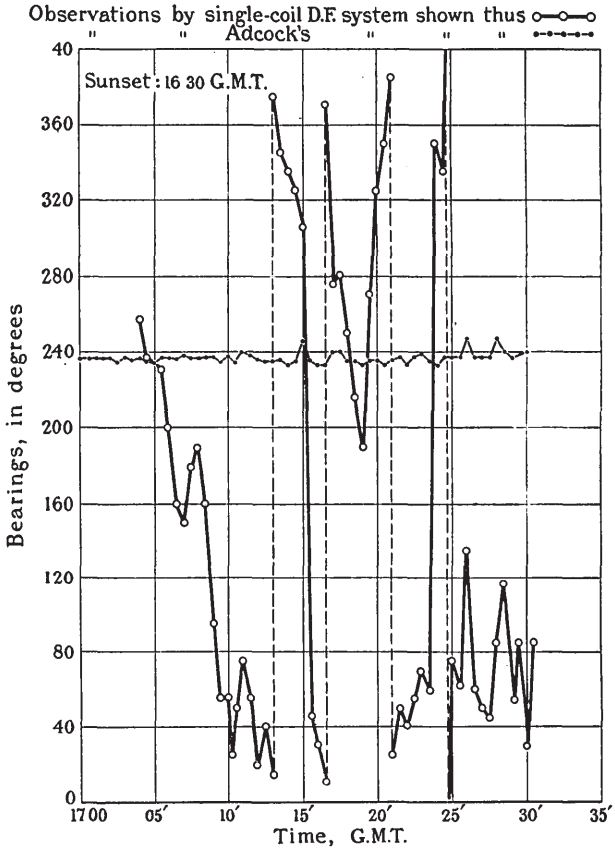

FIG. 6.—Observations of bearings on Bournemouth, 3 November, 1925 ($\lambda = 386$ m).

aerial. This last test brought to light a superiority of 2 or 3 per cent of the lower half over the upper half of each aerial, due probably to the difference in their capacities to earth. Although the error introduced by this asymmetry was very small, it could probably have been eliminated by suitably shortening the lower part of the aerial to make the two halves electrically equal. Since the whole method depends upon the assumption that the four receiving aerials are identical, it is important to observe that other tests showed that the receiving properties of the aerials was not materially influenced by slight differences or irregularities in the neighbouring supporting structures.

(6) CALIBRATION OF THE SYSTEM.

The apparatus was now calibrated for direction-finding by taking observations of the apparent bearings

of stations transmitting within the broadcasting band of wave-lengths, under conditions which gave freedom from night errors. In this manner it was found that the apparatus was subject to a permanent directional error of the same order as that experienced on the closed-coil direction-finders in use in the same field, due to the local surroundings.

(7) Determination of Lateral Deviation of Wireless Waves under Night Conditions.

In order to determine to what extent wireless waves can be laterally deviated from the great-circle plane connecting the transmitter and receiver, it was decided to make observations on some transmissions which were known to give rise to serious night variations on an ordinary direction-finder. Accordingly a series of tests was carried out in which the apparent bearing of a transmitting station was observed simultaneously on the above apparatus and on an ordinary single-coil direction-finder installed in another hut at about 100 yards' distance. In this manner observations were taken on the transmissions from Cardiff (353 m), London (365 m), Bournemouth (386 m), Newcastle (404 m), and Birmingham (475 m). The most serious night variations were obtained on Bournemouth and Cardiff, and Figs. 6 to 9 show graphically some of the results obtained in the simultaneous observations on these stations. Figs. 6 and 7 refer to the results obtained on Bournemouth on two different evenings; and these show very strikingly that the errors obtained on the Adcock system are almost negligible compared with those obtained on the single-coil direction-finder. Indeed, on several occasions, the latter system showed a rotation of the apparent bearing through more than 360°, whilst on the Adcock system the extreme variation in either of the tests was 14°. From the results on Cardiff plotted in Fig. 8 the same effect is observed, although the variations are less violent. On one occasion the bearing on the single-coil direction-finder rotated through 175°, whilst the extreme variation on the other system was about 7°. In the further observations on Cardiff plotted to a larger scale in Fig. 9, it is seen that when the normal direction-finding variation was comparatively small (14°) the extreme variation on the other set was 1°, which is of the same order as the limiting accuracy of the present apparatus.

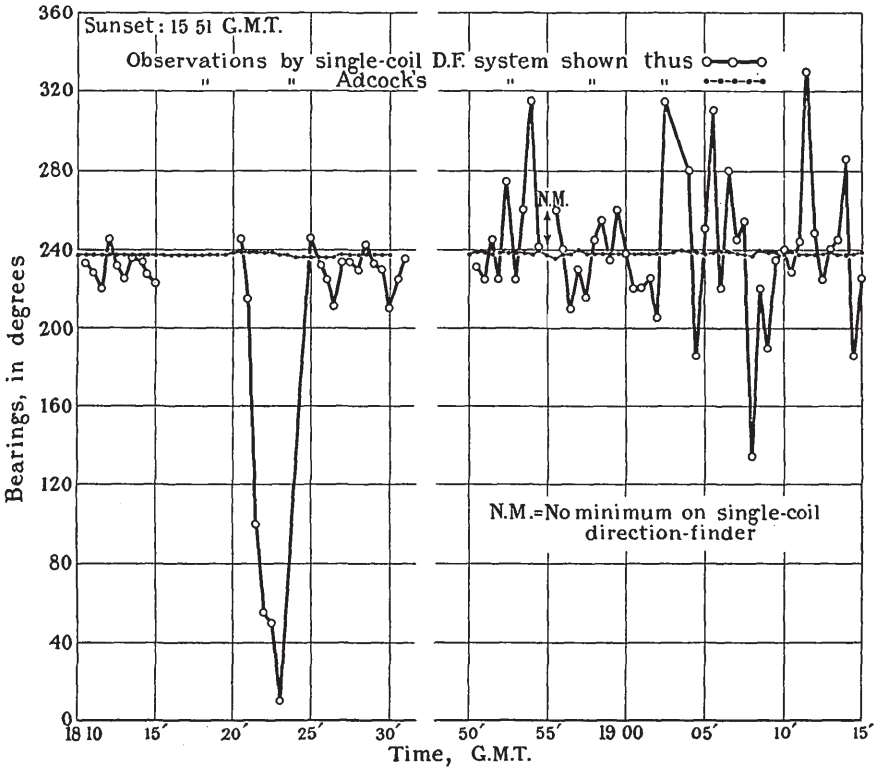

Fig. 7.—Observations of bearings on Bournemouth, 10 December, 1925 ($\lambda = 386$ m).

It is to be concluded from these results, therefore, that lateral deviation plays a negligible part in producing the large and variable errors in apparent bearings which are obtained at night on the present type of closed-coil direction-finding set; and that, therefore, these errors are entirely caused by the arrival of downcoming waves polarized with the electric force horizontal. We have, therefore, in this investigation a further proof of the existence of these downcoming waves which supplements and confirms those given in previous papers by Appleton and Barnett * and by the present authors.†

The slight residual variable errors noticed as having

* E. V. Appleton and M. A. F. Barnett: "On Some Direct Evidence for Downward Atmospheric Reflection of Electric Rays," *Proceedings of the Royal Society*, A, 1925, vol. 109, p. 621.

† R. L. Smith-Rose and R. H. Barfield, loc. cit.

been recorded on the "four aerial" system may, it will be seen, amount to $\pm$ 7°. These may be caused by a slight defect in the apparatus due to imperfect balancing by which the rotated downcoming wave is able to produce some slight current in the goniometer, or it may be actually a residual amount of lateral deviation. Before the point is settled by improvement of the apparatus it will be best to assume that it is due to the latter cause. The important point is, however, that

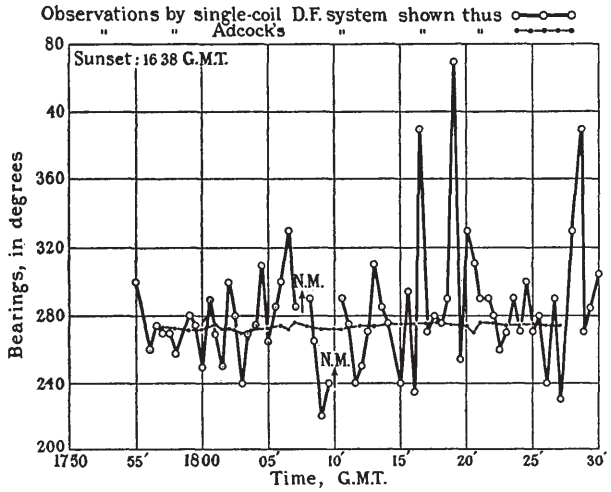

FIG. 8.—Observations of bearings on Cardiff, 26 January, 1926 ($\lambda = 353$ m).

even so, an error of $\pm$ 7° due to lateral deviation almost certainly does not imply that the waves are deviating to this extent from the great-circle path between transmitter and receiver, for it may be shown that, given two waves arriving with varying relative phase and with direction of travel in vertical planes separated by an angle ψ, the total maximum apparent variation in the resultant direction will greatly exceed ψ.* The conditions for this occurrence are simply that the two waves shall be approximately equal in amplitude and nearly 180° out of phase. It then appears extremely probable that the $\pm$ 7° apparent variation recorded is an indication of a much smaller real lateral deviation.

It may further be pointed out that a slight lateral difference in path between the horizontal and downcoming wave is almost certain to exist, for the horizontal wave on land is nearly always slightly deviated by local irregularities of the earth's surface (trees, etc.), whilst the downcoming wave on the other hand will not be influenced by these causes, at any rate to the same extent, and thus the two will probably not arrive exactly in the same vertical plane.

It is to be observed that, since there is no departure of the downcoming wave from the great-circle plane connecting tramsmitter and receiver, it is unlikely that the upper ionized layer, from which this wave is returned to the earth, is inclined to the horizontal. Such a tilt of the upper deflecting layer was suggested by Eckersley † as a possible cause of the downcoming wave having a component polarized with the electric force in the horizontal plane. Further, since it has previously been shown that directional errors are obtained on the transmissions from a vertical aerial,* it is evidently unnecessary for the horizontal electric force to be present in the radiation from the source. The investigations described in the present paper thus form a useful confirmation of the magneto-ionic theory of wave propagation which has been recently introduced by Appleton and Barnett † and by Nicholls and Schelleng,‡ in which the rotation of the plane of polarization of the downcoming waves is ascribed to the influence of

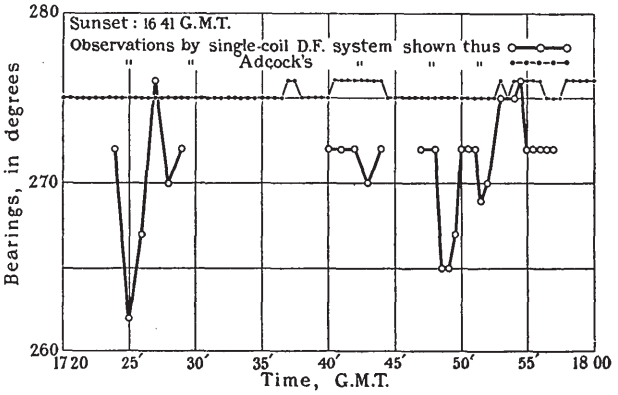

FIG. 9.—Observations of bearings on Cardiff, 28 January, 1926 ($\lambda = 353$ m).

the earth's magnetic field on the motions of the ions in the upper atmosphere.

(8) APPLICATION OF THE SYSTEM AS A DIRECTION-FINDER FREE FROM NIGHT ERRORS.

In the experiments described above it has been demonstrated that Adcock's four-aerial directional receiving system is successful in discriminating between laterally deviated waves and horizontally polarized downcoming waves. It is further shown that even during the times when the worst variations of bearings are obtained on the closed-loop direction-finding systems, the amount of actual lateral deviation of the arriving waves is very small. It therefore follows that such a system may be used as a direction-finder which gives the true direction of the great-circle plane of arrival of wireless waves whatever may be their state of polarization or their angle of incidence relative to the earth's surface. The system should, therefore, have important applications as an accurate direction-finder under night conditions, or for use in observing on aircraft at high angles of elevation, when the ordinary closed-loop direction-finder is subject to such large errors as to make it practically useless. For example, Baldus and Buchwald § have shown that the closed-coil direction-finder

* See, for example, T. HEILIGTAG: "On the Causes of Error in Directional Reception," *Jahrbuch der drahtlosen Telegraphie und Telephonie*, 1923, vol. 21, p. 77.

† T. L. ECKERSLEY, loc. cit., p. 239.

* R. L. SMITH-ROSE: "The Effect of the Shape of the Transmitting Aerial upon Observed Bearings on a Radio Direction-finder," *Journal I.E.E.*, 1924, vol. 62, p. 957.

† E. V. APPLETON and M. A. F. BARNETT: "Wireless Wave Propagation," *Electrician*, 1925, vol. 94, p. 398.

‡ H. W. NICHOLLS and J. C. SCHELLENG: "Propagation of Electric Waves over the Earth," *Bell System Technical Journal*, 1925, vol. 4, p. 215.

§ R. BALDUS and E. BUCHWALD: "Experiments on the Wireless Orientation of Aeroplanes," *Jahrbuch der drahtlosen Telegraphie und Telephonie*, 1920, vol. 15, p. 214.

on the ground can give errors of as much as 60° in the bearings of aircraft.

In considering what will be the limiting accuracy of such a system it must be remembered that the variable error of $\pm 7°$ mentioned above was obtained under what are probably the worst conditions that can prevail in wireless direction-finding on medium wave-lengths. For it is worthy of note here that the variations of apparent bearing observed at Slough on the transmissions from Bournemouth are very much greater in both frequency and magnitude than any hitherto experienced by the authors during the past five years on all wave-lengths from 450 to 12 000 m. Under more favourable conditions, such as obtained in the case of the results taken on Cardiff, the maximum error experienced was only 2° or 3°, and it is considered that even this small amount can be reduced by a development of the system on a more favourable site. Also, on the longer wave-lengths allocated for commercial direction-finding the system will be subject to a still smaller error, and the instrumental difficulties will be somewhat decreased.

It is of course realized that in the practical development of the system it would be preferable to have the receiving apparatus, together with the operator, located on or near the ground and not at the centre of the aerial system as represented in Fig. 4. Several methods of overcoming the difficulties mentioned in Section 3 (*b*) have already occurred to the authors and these will be tested experimentally as soon as possible. A consideration of the case also shows that the system may be provided with the sense-finding modification, which is now a usual attachment to all direction-finders.

(9) Conclusion.

The experiments have shown that by paying careful attention to symmetry of construction, the system of direction-finding proposed by Adcock can be made to work with a considerable amount of success.

It has been employed as a means of discriminating between laterally deviated and horizontally polarized downcoming waves, demonstrating within the limits of experimental error that lateral deviation was non-existent and that, therefore, the latter type of wave was responsible, in all the cases examined, for the whole of the errors experienced at night in the closed-coil direction-finding system.

These experiments thus constitute an entirely self-contained proof that at night time there are waves arriving in a downward direction polarized with the electric force in a horizontal plane.

It has been shown that good reasons exist for the hope that this system may be successfully developed into a direction-finding system free from night errors and "aeroplane" effect.

These investigations were carried out for the Radio Research Board, established under the Department of Scientific and Industrial Research, and the authors desire to acknowledge their indebtedness to the Board for permission to publish the results. They also wish to thank Mr. R. Naismith for his assistance in the later portions of the experiments described in the paper.

APPENDIX.

Some Early Observations on Aircraft with the Four-Aerial Direction-finder.

By Frank Adcock, M.B.E., B.Sc.

It was suggested that as all the authors' observations were obtained on land transmitting stations it would be of interest for me to add an account of some experiments which were made with direction-finders on transmissions from aeroplanes in 1918. It was known at that time that bearings or directions obtained by means of the ordinary "closed loop" direction-finders were often quite inaccurate or indeterminable. Experiments with a Hertzian oscillator and with a small spark transmitting set fitted with two equal and symmetrically disposed aerials instead of the more usual aerial and earth arrangement confirmed the view that the vagaries of the ordinary direction-finders were due to the presence of a horizontal component in the electric force of the radiation emitted by an aeroplane in flight. Further, it was thought that this horizontal component

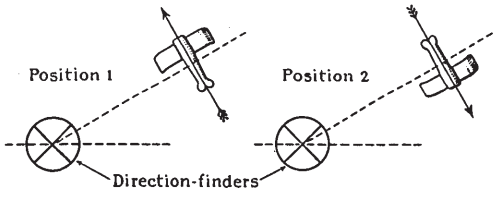

Fig. 10.

of the electric force of the radiation owed its existence to the two following independent causes :—

(1) An appreciable angle of incidence of the radiation in respect to the ground would cause the wave-front to lean forward.

(2) Owing to the drag of the aerial of an aeroplane in flight the axis of the "equivalent Hertzian oscillator" of the machine would depart considerably from the vertical. Under these conditions the horizontal electric component from this cause would be non-existent when the aeroplane was flying directly towards or away from the examination point, but would attain its maximum value when the machine was flying tangentially in respect to the observer.

The tests mentioned below were made with the aid of an aeroplane flying at a moderate altitude and at distances of 3 to 8 miles from the direction-finding installations, in which circumstances it was believed that any errors of direction would be associated almost entirely with the direction of flight of the machine. Two direction-finding installations were used for taking simultaneous observations on the aeroplane, one equipped with a revolving loop aerial, the other with the fixed experimental aerials devoid, as far as possible, of effective horizontal members. The two installations were erected close to one another but not so near as to cause

mutual interference. It was then arranged that the aeroplane fitted with a wireless transmitter should fly over a village in a direction at right angles to that of an imaginary line joining the village in question and the direction-finders. A return journey was then made over the same village, the aeroplane flying in the opposite direction. Wireless transmission took place when the machine was directly over the village, and the two positions of the aeroplane with respect to the direction-finders are shown in Fig. 10. The whole process was repeated over four villages situated at gradually increasing distances from the direction-finders, and the errors in the wireless bearings obtained in each case by both installations are indicated in the table above.

The results were meagre but it was clear that large and consistent errors were present in the bearings obtained with the revolving-loop direction-finder. On the other hand the apparatus fitted with the four vertical aerials gave errors in the bearings of only about one-fifth this magnitude. It was also of interest that the errors in the bearings taken with the revolving-loop direction-finder were reversed when the direction of flight of the transmitting aeroplane was reversed, and that these errors showed little tendency to diminish as the distance between the aeroplane and the direction-finder was increased.

TABLE.

Aeroplane flying over	Approximate distance of aeroplane from both direction-finders	Approximate true bearing of aeroplane from both direction-finders	Erorr of bearing on aeroplane as recorded by direction-finder with revolving-loop aerial		Error of bearing on aeroplane as recorded by direction-finder with four vertical aerials	
			Aeroplane in position No. 1 (Fig. 10)	Aeroplane in position No. 2 (Fig. 10)	Aeroplane in position No. 1 (Fig. 10)	Aeroplane in position No. 2 (Fig. 10)
	miles					
Village A	3	65°	—	− 21°	—	+ 1°
Village B	4	67°	+ 24°	− 33°	− 1°	− 6°
Village C	5½	66°	+ 31°	− 23°	− 3°	− 5°
Village D	8	63°	+ 40°	—	− 2°	+ 1°

The authors have made a very comprehensive examination of the wireless radiation from land stations under various conditions and if they can be induced to extend their investigations to a thorough examination of the radiations emitted from elevated sources, the publication of my own scanty observations will be justified.

DISCUSSION BEFORE THE WIRELESS SECTION, 5 MAY, 1926.

Mr. R. H. Barfield : I should like to point out one or two details which have occurred to Dr. Smith-Rose and myself since we wrote the paper, and also, perhaps, to forestall one or two of the more obvious criticisms to which the paper might otherwise be subjected. In the first place the system clearly has an application as an ordinary directional receiver, i.e. one in which its directional properties are made use of to minimize interference. Most of the established methods of directional reception work on the assumption that the waves are vertically polarized and they therefore break down when this is not the case. The present system has not this disadvantage and should therefore be an improvement as a method of reducing jamming or atmospherics at a receiver. For we now know that signal waves may often be circularly polarized and it is at least highly probable that atmospherics sometimes also are. There is certainly no evidence to the contrary. A criticism might well be raised that the Adcock direction-finding system could not possibly be worked in practical circumstances owing to the delicacy of the balancing required which might be upset by the presence of surrounding objects. Now for the successful working of the new system much the same conditions are required as for any other direction-finder. The two essentials are : (1) That the instrument shall be designed correctly to work in accordance with its theory, and (2) that a minimum space shall be provided round the system free from all conductors and of homogeneous or symmetrical dielectric properties, or, failing this, one in which all the electric properties remain constant. As regards the first of these I think we may now claim to have satisfactorily solved the problem of design. For the second, the dimensions of the minimum space will probably vary with the wave-length and the point remains to be investigated. So far, however, there is no evidence that the Adcock system requires any more space than any other direction-finding system ; nor does there seem to be any particular reason why it should. In connection with the space occupied by the system, it has probably occurred to some that the arrangement we have described is not the most fundamental form which the system can take. The simplest arrangement would consist of a single pair of opposed aerials mounted rigidly on an arm so as to rotate about a vertical axis (see Fig. A), and which would take the form of a metal pipe down which the leads would be brought to a screened box on the ground. The circuit

diagram would be much the same as with the four-aerial system (Fig. B). The tuned circuit and the amplifier would be contained in a screened box forming the base of the apparatus. The advantage of this arrangement is that it might be made much smaller than the four-aerial system, to which it bears exactly the same relation as the closed-coil direction-finder bears to the Bellini-Tosi system. There does not seem to be any doubt that such a system as this will work satisfactorily, but we have not yet had time to try it. Returning finally to the four-aerial system, since the total signal strength obtained is the result of the small differential action of two identical aerials connected in opposition, and, further, since the aerials are not even directly tuned and are of dimensions too small to be efficient except for very short waves, it might well be questioned whether the apparatus had not attained its perfect directional properties by making too great a sacrifice of its range of working. As a matter of fact this is not at all the case. The daytime range obtained with the apparatus just described is over 200 miles to a standard B.B.C. station, but this is far from being a maximum range. This apparatus was not constructed from this point of view at all; not only could its aerial system be greatly

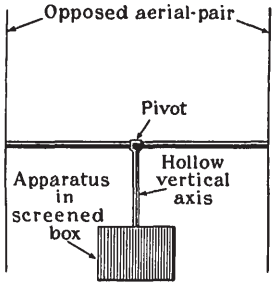

FIG. A.

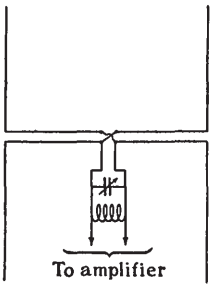

FIG. B.

improved in efficiency if necessary, but by the use of modern amplifying apparatus alone the range could without doubt be greatly increased. Thus the question of the range of the Adcock system in comparison with that of other systems is not likely to arise.

Admiral of the Fleet Sir H. B. Jackson: I should like to congratulate the authors on the results they have obtained after many years of labour in getting a directional system which may be free from night errors. I hope that they will be able to make of it a practical working instrument suitable for replacing the present Bellini-Tosi ones in places where they are erected. The Radio Research Board agrees with the results of these experiments. What the effect would be on the coil system on board ships it is difficult to foresee, but I think that if the night errors can be reduced to nil—they are not very great at present on the distances used at sea, it is true—it will be a great improvement and enable reliable bearings to be obtained at night at much greater distances than at present.

Mr. R. Keen: Although the paper is very interesting, I read it with mixed feelings. The authors make reference to the work of previous adherents to the Eckersley theory, but they fail, I think, to make clear that much of the confirmation which they bring forward had been produced in almost identical form by these earlier writers. Under the heading "Objects of the present paper" the authors say: "This portion of the work has recently led to a definite proof of the existence of downcoming waves at the earth's surface with components of suitable polarization and sufficient intensity to account for a large proportion of the night errors experienced." With regard to this, I think that Eckersley, in his original article in the *Radio Review* * gave very good proofs that the errors were caused by these downcoming waves with abnormal polarization, and, in addition, the article by Wright and Smith, to which the authors refer, afforded a number of examples of the 360° rotation of bearings similar to those now shown in connection with Bournemouth. In 1920 Wright and Smith were taking bearings at Chelmsford on Clifden which at that time was working on 6 000 m (C.W.) and also on Lyons on a 5 000-m arc transmission. One of the Clifden error curves shows that there was a tendency for the rotation to occur at intervals of approximately 20 minutes and this was the period which would be expected to elapse between two cycles of interference between the direct and reflected waves as the Heaviside layer was rising. The Bournemouth rotations on a much shorter wave-length appear to be at 4-minute intervals. Another instance of 360° errors is referred to briefly in my book † when dealing with the confirmation of the Eckersley theory. When the Marconi Co. originally started their wireless service to Paris, reception at this end was carried out on a Bellini-Tosi aerial with a figure-of-eight diagram, the wave-length being 2 300 m. Before the heart-shaped diagram was substituted for the figure-of-eight, complete rotations of the bearing of Paris were not unusual near the time of sunset, and on one evening in 1921 the apparent bearing of Paris made $3\frac{1}{2}$ complete rotations within an interval of 15 minutes. On the assumption that these rotations are due to interference between the direct and reflected rays, then at the instant of maximum error there should be a drop in signal strength since the direct ray and the normally polarized component of the reflected ray are in phase opposition. Signal-strength measurements were accordingly made on Clifden by Wright and Smith, and the intensity was found to fall as the error increased, and in certain cases dropped almost to zero at the instant of 90° error. I do not wish to appear too critical, but I think it right to emphasize that these 360° rotations of bearing were well known 4 years ago, and I consider it hardly correct for the authors to say that "it is now evident that these variations are caused by the action of the horizontal components of electrical force in the downcoming waves," etc.; because many of us were convinced of this after the previous work on the subject was published. The results obtained with the Adcock aerial system are extraordinarily interesting, and the graph of Fig. 6 must surely be the first to be published showing such a complete conquest of night variations. If the system can be put into a more practical form, whilst retaining its accuracy, it should be of great commercial value. The Marconi Co. made

* T. L. ECKERSLEY: "The Effect of the Heaviside Layer on the Apparent Direction of Electromagnetic Waves," *Radio Review*, 1921, vol. 2, pp. 60 and 231.

† R. KEEN: "Direction and Position Finding by Wireless," 1922, p. 164.

some tests on the Adcock system some years ago using the arrangement shown in Fig. 2, but wave-lengths of several thousand metres were used. This made the whole operation rather more difficult, although trouble with the screening cage disappeared since underground cables could be used. The work had to be abandoned before any success was achieved approaching that now recorded by the authors. It would be interesting to know whether a capacity radiogoniometer has been tried in place of the inductive one. Since open aerials are being used, there might possibly be some advantage in doing so. Mr. Barfield has mentioned the use of the Adcock system for directional reception, as by its means a heart-shape minimum can be maintained under the worst night-effect conditions. It should certainly be very useful in this connection, but at the same time it is an uncommon thing in this country for the downcoming ray, on wave-lengths between 2 000 and 20 000 m, to be so steep as to upset the normal closed-coil heart-shape balance. At the Marconi receiving station at Brentwood there are 14 receivers employing heart-shape reception and it is only rarely necessary to alter adjustments due to this cause, although at some Continental stations where the district is mountainous a certain amount of trouble is experienced at sunset in maintaining the minimum for the elimination of jamming. It is mentioned on page 150 that: " The investigations . . . form a useful confirmation of the magneto-ionic theory of wave propagation which has recently been introduced by Appleton and Barnett and by Nicholls and Schelleng, in which the rotation of the plane of polarization of the downcoming waves is ascribed to the influence of the earth's magnetic field on the motions of the ions in the upper atmosphere." I think, however, that some credit for this should be given to Dr. Eccles who, in his Inaugural Address * to the Wireless Section in 1921, said that the action of the earth's field on free electrons in space would account for the rotation of the plane of polarization to this extent. I am glad that the authors have now experienced some of these violent variations on C.W. signals, because they will appreciate why it was that in discussions on their previous papers on night variations I have always insisted that errors were greater on C.W. than on spark. Having seen, on various occasions, the apparent bearing of a station move through 360°, makes one prejudiced against long-distance C.W. bearings with a closed-coil direction-finder. Lest this paper should, however, give the impression that all direction-finding is unreliable, it must be remembered that the authors were deliberately searching for bad night effect and that it has been proved by their previous tests that, up to 100 miles over sea, either spark or I.C.W. transmission will give all the reliability required for the navigation of ships.

Mr. J. M. Furnival: The authors refer to inaccuracies of bearings received by ground direction-finding stations from aircraft in flight. The tests mentioned in the Appendix were made with the aid of an aeroplane flying at a moderate altitude and at distances of 3 to 8 miles from the direction-finding installation. The tabulated data would appear to indicate considerable errors observed on a revolving-loop direction-finder, and it is furthermore stated that these errors showed little tendency to diminish as the distance between the aeroplane and the direction-finder was increased. It may be of interest to compare the results thus obtained experimentally under the conditions described with those achieved by the Bellini-Tosi ground direction-finding stations which have been in operation for the past 4 or 5 years in connection with the navigation of civil aircraft on the cross-Channel air routes. It may be explained that Bellini-Tosi direction-finding stations have been established for this purpose by the Air Ministry at Croydon, at Pulham in Norfolk, and lately at Lympne in Kent. Similar stations have also been arranged at various important air stations in Europe. The results of several years' experience show very definitely that during daylight hours an accuracy of within 1½° can be normally expected. Due to the speed of approach of the aircraft, which in any case makes the passing of bearings at close ranges an operation of some difficulty, any errors which may exist when the aeroplane is in close proximity to the station have not in practice been detrimental to the service to any appreciable extent. The great value of this service to aerial navigation is now well established, and this is borne out by the experience gained by pilots both in practice and also when flying in conditions of bad visibility. [The speaker here quoted extracts from numerous reports, by permission of the Air Ministry.]

Mr. F. Adcock: I am rather out of touch with " wireless " as applied to aircraft at the present time, and it is possible that a modern aeroplane carries a fairly heavy weight on its aerial, in which case the angle taken up by the aerial when unwound may be nearly vertical. That would have the effect of bringing the bearings much nearer the truth. In the actual tests that were made, we set out to obtain the largest possible errors (with the ordinary direction-finders) and the experiments were carried out in 1918 with that object in view. We did not use the Bellini-Tosi but the revolving-loop system. I take it that the Bellini-Tosi apparatus should be subject to similar errors.

Mr. E. H. Shaughnessy: Judging from the curves shown, although the Adcock direction-finder does vary, it does not seem to vary in the same way as the coil. Where there is a maximum deviation in the coil in one direction, the curve for the Adcock aerial seems to bend in the opposite direction. This seems to be common to all the curves. Is there any reason for this? The phenomenon can be clearly seen in Fig. 8 just after 18 20 G.M.T. and at 18 05 G.M.T. I take it that an error of 7° on a direction-finder is almost as bad as one of 50°. It seems, therefore, that unless the error can be reduced to, say, not more than 2°, the bearing cannot be relied upon and that the system is no better than the Bellini-Tosi. With regard to the day error, our practice with the Bellini-Tosi system shows we can get quite good results within 2°. Moreover, when we get these installations at shore stations calibrated by means of the ships the navigating officers say that they cannot get nearer than 2° in their calculation unless they have objects on land on which to take sights, which indicates that there is little to choose between compass bearings and wireless directional bearings.

* *Journal I.E.E.*, 1921, vol. 59, p. 83.

Lieut.-Col. H. P. T. Lefroy: The authors have not mentioned the subject of fading. If fading can be reduced by using the Adcock aerial, it might become a valuable form to use for broadcast reception. Referring to Fig. 5, would it be possible to get any compensation for asymmetry by sliding the connections of the lower antenna, leaving the upper connections fixed on the ends of the goniometer coil ?

Prof. J. T. MacGregor-Morris : Why does the bearing of the Bournemouth station show such excessive variations as compared with other stations which have been tested ? One speaker in the discussion has mentioned that it is not only a question of rather limited changes of wave-length, because he gave an example of a wave-length of 6 000 m where there was a revolution of this kind. Referring to Fig. 6, apparently the direction from which the received wave has come has undergone two complete revolutions and then has turned back through the same number of revolutions, as if it had to uncoil itself. Is this borne out by other observations ? The variations of bearing shown in this figure are very striking. They are taken, I understand, on the direction in which the waves appear to come from Bournemouth at Slough. If simultaneous observations were taken at Bournemouth when Slough was radiating, would the converse hold good ?

Major B. Binyon : I am very interested in what Mr. Barfield said with regard to future developments, because it seemed to me he was very confident on the sensitivity question. I should like to ask him if satisfactory signals could be received on an Adcock direction-finder having aerials of approximately the size of coil direction-finders as now used for ships. With regard to the disturbing effect of stray capacities in the original arrangement as shown in Fig. 2, in that sketch the two parallel horizontal leads are shown very far, apart; this may be only a matter of draughtsmanship, but it seems to me that the distance between the leads could be made absolutely negligible in comparison with their distance from the ground. This should reduce the asymmetry produced by capacity to earth. I presume that the $\pm$ 7° errors in bearings on Bournemouth, etc., were taken with the Hertzian oscillator apparatus. What would be the magnitude of the errors if the arrangement shown in Fig. 2 were used; would the horizontal effect be much worse ?

Dr. S. H. Long (*communicated*): I should first like to emphasize the valuable scientific contribution by the authors to the vexed question of the reflected polarized down ray and its resultant effect of producing "night-effect" errors in direction-finding work. The apparatus as designed and described certainly appears to offer immense possibilities for employment in cases where suitable care can be taken to ensure its being erected on a most favourable site where ample space and other facilities are available. It would then be of great importance to the safety of aerial and marine navigation, and it is for those purposes, I consider, that it appears to be specially adapted. I feel, however, that one should not overlook the present tendency in marine wireless direction-finding to install the apparatus on the ship rather than on the shore, and the ever-increasing number of radio beacon stations seems likely to encourage that tendency in the future. Now on board ship the conditions are very different from those on land. The apparatus has to be installed in a situation which is convenient to the general working of the vessel and which has in the majority of cases not been in any way selected for efficient wireless direction-finding. Further, the mere presence of the metal mass of the ship is an influence which may give results comparing unfavourably with those described by the authors. The space available for the installation is invariably limited, especially on cargo vessels where interference must not be caused to the working of cranes and cargo hoists. In the past it has been an unfortunate practice of navigators to demand a direction-finding bearing when night effect has been present and the wireless operator has taken, if minima were possible, one or two bearings and either cancelled them or sent them to the bridge marked "night-effect." Naturally in a large number of cases these results have caused wireless direction-finding apparatus to be regarded as unreliable for navigation purposes. Experience, however, shows that if a direction-finding set is designed to indicate the actual presence of night-effect, and the operator does not take one but a large number of bearings over a period of 5 mins., then the mean bearing is sufficiently accurate to be a valuable aid to navigation. The usual procedure now adopted when night-effect is present, on one large liner employing a single-coil direction-finding set with suitable compensating devices when making New York, is for the operator to submit a list of bearings on Nantucket at each sending period. All these bearings are submitted to the navigator, who can obtain a large degree of accuracy from the mean bearings. The following example is that obtained on such a liner when night effect was so bad that the shore station refused to give a bearing.

Time, G.M.T.	Maximum	Mean bearing	Difference against visual checks
15 20	272°	267·5°	+ 0·5
15 25	263°		
	272°	267·5°	+ 0·5
	263°		
15 30	272°		
	262°	267°	± 0·0

Thus, in practice, provided bearings over a period of 5 mins. can be taken—and this is nearly always possible on direction-finding beacon stations—the "night-effect" does not become a really definite drawback. It is, of course, essential that both wireless operators and navigators should fully understand the problem. When examining Fig. 6 it appears at first glance that the night-effect difficulty with regard to the use of the direction-finder as an aid to marine navigation has been overcome, but on closer consideration it appears that there is a residual amount of lateral deviation which may amount to $\pm$ 7°. It seems doubtful whether, as

a point of practical navigation, it would not be preferable to continue to employ a direction-finder suitably designed so that unreliable bearings could be immediately recognized as unreliable, rather than a direction-finder which gives a definite reading which may or may not be subject to a deviation of ± 7° from the apparent bearing. I should like to ask the authors how the bearings given in the paper were actually taken. If they were taken on the carrier wave, by what method was the oscillator introduced into the single-frame and the Adcock systems? Moreover, what was the "arc of swing" in obtaining the bearings? With the increasing number of C.W. installations, and the desirability of obtaining accuracy on C.W. stations, I should think that the interaction of 5 frames as used by the authors (i.e. 2 main aerials, 2 field coils and 1 search coil) would render the system somewhat difficult to design for the accurate taking of C.W. bearings. Moreover, in "sense" determination—and this is essential in all modern direction-finding work—the phasing of the waves in the frame systems must be exceedingly complicated, and, as the whole sharp determination of "sense" is dependent on the accurate balancing of phasing in the systems, this problem does not appear capable of a simple solution such as can be obtained by the single-frame system.

Dr. R. L. Smith-Rose and **Mr. R. H. Barfield** (*in reply*): Mr. Keen has taken us to task for presuming to claim priority in the matter of the proof that night errors in direction-finding are due to the arrival of downcoming waves horizontally polarized. We would reply, however, that no such claim was intended. Full references are given in the paper to the work of all those mentioned by Mr. Keen, and, whilst we fully recognize the value of such work, others besides ourselves have considered that further confirmation was necessary. As a result of the research for such confirmation we think it will be agreed that our knowledge of the influence of the upper atmosphere on wireless transmission has been very materially enhanced. We must further emphasize that the present paper contains the first proof that wireless waves travelling around the earth, whether directly or via the upper atmosphere, suffer no appreciable lateral deviation from great-circle planes, a possibility to which attention was drawn in Mr. T. L. Eckersley's paper.* In final defence we would also remind Mr. Keen that there are still individuals, both within and outside this country, who are sceptical about the Heaviside layer.

On the question of the complete rotation through 360° of a signal minimum on a direction-finder, the following quotation may be given from a report † on an investigation on the variations of bearings of transmitting stations, both spark and continuous wave, operating at various distances on wave-lengths between 2 000 and 12 000 m. "The largest error recorded during the whole two years' observations was over 105°, but errors of this magnitude were extremely rare, and out of the 164 000 observations tabulated only in three cases was an error exceeding 90° experienced." In a later report * dealing with the continuation of the investigation on wave-lengths down to 450 m it was stated that "the maximum observed error on any station was 82·7°." This experience conflicts somewhat with that mentioned by Mr. Keen, and we must repeat that we still consider a rotation of bearing of more than 90° an exceptional occurrence. Even now we have only experienced a rotation of 360° in the case of Bournemouth's transmissions received at Slough, although observations have been made on several other of the British Broadcasting Co.'s stations on neighbouring wave-lengths. The condition for such rotations is evidently a critical one and depends upon getting the wave-length, the relative intensities of the direct and downcoming waves, and the polarization and angle of incidence of the latter, all of the right order. Owing to the fact that observations under identical conditions have not been made on damped-wave transmissions, we cannot agree with Mr. Keen that these results in any way affect the question of the relation between wave-damping and directional errors. All these points, however, would appear to be somewhat irrelevant to the main object of the paper, which, as Mr. Keen appreciates, has been to demonstrate the utility of the Adcock system in overcoming night errors in radio direction-finding.

From Mr. Furnival's remarks we gather that the only difficulty experienced in practice in the operation of ground direction-finding stations for observing the bearings of aircraft is in the matter of night errors. This would therefore seem to be a good case for the application of the Adcock system, which has the additional advantage that, *if necessary*, it can be used for accurate bearing observations at short ranges.

We think that the coincidence between the maximum deviations in opposite directions on the single coil and Adcock systems pointed out by Mr. Shaughnessy is accidental, for it does not always occur in the diagrams given in the paper (cf. Fig. 6 at 17 25–17 30). We do not consider that an error of 7° is quite as bad as one of 50°, but there seems to be every hope that the error of the Adcock system may be reduced to 2°, which is quite adequate for most navigation purposes at the present time.

In reply to Lieut.-Col. Lefroy, the fading of signals received on the Adcock aerial system should be of the same order as that experienced on any vertical aerial, since in both cases it is due to the variation in the intensity of the vertical electric force in the arriving waves. Since the Adcock system does not receive waves polarized with the electric force horizontal, the fading effects may not be quite the same as those experienced with an inverted L or a T aerial, but it is doubtful if any material advantage for broadcast reception is to be gained in this manner.

On the subject of the excessive variations in the bearings of the Bournemouth station, we would refer Prof. MacGregor-Morris to our reply to Mr. Keen above. The curious behaviour of the variations noted in Fig. 6 has not been confirmed by other observations. We regret that we have at present no data that will

* *Radio Review*, 1921, vol. 2, p. 239.

† R. L. Smith-Rose: "Variations of Apparent Bearings of Radio Transmitting Stations," Part II, Radio Research Board Special Report No. 3, 1925, p. 103.

* R. L. Smith-Rose: "Variations of Apparent Bearings of Radio Transmitting Stations," Part III, Radio Research Board Special Report No. 4, 1926, p. 48.

enable us to answer the question as to the reciprocity of transmission between Bournemouth and Slough.

Major Binyon is correct in assuming that the horizontal leads in Fig. 2 are shown well separated for the purpose of clarity. In practice these leads should be as close together as is compatible with a small capacity between them. Having established the validity of the principles underlying the Adcock system and the fact that the lateral deviation of wireless waves is negligible, with the aid of apparatus represented diagrammatically in Figs. 4 and 5, we are now returning to the arrangement depicted in Fig. 2 with a view to removing the defects formerly experienced in its practical operation. While it may be difficult to reduce the dimensions of the system to that of a small frame coil, we see no reason why future development should not result in an Adcock direction-finder of suitable size for installation on board ship, and with adequate range for navigation purposes.

In reply to Dr. Long it would appear that on any direction-finding system which is subject to variable night errors the existence of these errors can be detected by taking successive observations over the space of several minutes. We agree entirely that the effect of a night error can be considerably reduced by taking the mean of such observations. On the medium wave-lengths employed for navigation purposes a period of 5 to 10 minutes will probably be sufficient for such a series of readings, but on the longer wave-lengths of from 2 000 to 20 000 m a night error may remain comparatively constant for $\frac{1}{2}$ hour at a time. It has been consistently pointed out, however, in previous publications * that over long periods the mean bearing at night is seldom more than 1° or 2° in error, although individual observations may be subject to errors up to 60°. Considering that the experiments described in the paper constitute the first systematic test of the Adcock system, we feel justified in assuming that an extreme error of 7° under the worst conditions for direction-finding is an extremely favourable beginning; and we feel confident that the system will in due course play its part in the application of direction-finding to navigation. All the bearings recorded in the paper were observed on the carrier wave of the broadcasting station concerned, a beat note being obtained by introducing oscillations from a local source. This source is adequately screened in a manner previously described.† A standard form of such screened oscillator has now been in use for continuous-wave direction-finding for several years and it has given every satisfaction for this purpose. We can assure Dr. Long that, provided correct precautions are taken with the apparatus by applying now well-known principles, there is no reason why direction-finding on continuous waves should not be quite as accurate as with damped waves (spark or interrupted continuous waves). Mr. Barfield has already drawn attention in this discussion to the possibility of the Adcock system being made quite as simple as the single-frame system, and this is one of the lines which future development will take.

* R. L. Smith-Rose: "Variations of Apparent Bearings of Radio Transmitting Stations," Radio Research Board Special Report No. 2, 1924; No. 3, 1925; No. 4, 1926.

† R. L. Smith-Rose: "On the Electromagnetic Screening of a Triode Oscillator," *Proceedings of the Physical Society of London*, 1922, vol. 34, p. 127.